REFERENCE COPY

PATENT SPECIFICATION

628,547

Convention Date (United States of America): Oct. 31, 1944.

Application Date (In United Kingdom): April 3, 1946. No. 10274/46.

Complete Specification Accepted: Aug. 31, 1949.

Index at acceptance:—Classes 40(v), WG; and 40(viii), U18a(1: 2: 4), U18b1.

COMPLETE SPECIFICATION

Improvements in or relating to Ultra-High Frequency Electrical Transmission Systems

...CORPORATION, a corpor- ... the ...

PATENTS ACT, 1949

SPECIFICATION NO. 628547

Reference has been directed, in pursuance of Section 8 of the Patents Act, 1949 to Specification No. 656237.

THE PATENT OFFICE,
7th July, 1952

trical ... particularly relates to a ... selector for separating two waves travelling in opposite directions in a wave guide, coaxial or parallel wire transmission line.

In transmission engineering much use is made of the concept of incident and reflected waves. These two waves can exist whenever energy is being transmitted from a generator to a load over a transmission system which may be a wave guide or a coaxial cable or a two-wire transmission line.

The incident wave is a radio wave which travels along the transmission system from the generator to the load, and in so doing carries energy towards the load. The reflected wave is a similar radio wave which travels from the load towards the generator, and in so doing carries energy back towards the generator. Thus the energy which is carried towards the load by the incident wave is divided into two parts at the load. One part is absorbed by the load and the other part is reflected back towards the generator and constitutes the reflected wave.

The energy which is absorbed by the load is useful energy since the load performs some useful function such as radiation of the energy towards a receiving station. On the other hand, the energy which is reflected back towards the generator in the transmission system ordinarily has no usefulness. In fact, it reduces the efficiency of the transmission ... of losses which accom- ... trans- ... ing the metal of the ...

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Thus, if the reflected wave is of a magnitude which is appreciable compared to the incident wave, extra power losses will occur in the transmission system and the efficiency of transmission will be lowered.

The amount of reflection which will occur at the load can be expressed in terms of the impedance of the load as compared to the characteristic impedance of the transmission system. If these are equal, there will be no reflection and thus no reflected wave. If they are unequal, the amount of reflection, as well as the change in phase angle as a result of reflection, will depend on the complex ratio of the load impedance to the characteristic impedance.

When an incident and a reflected wave are both travelling in a transmission system, it is found that they interfere with one another. At each position along the transmission system the amplitude of the field strength will have a value which is different from the value of the amplitude of the field strength at a nearby position slightly displaced along the transmission system. This variation is periodic along the transmission system, having a period of a half wave length, (the wave length being that in the trans-

[*Price* 2/-]

Price 4s 6d

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COMPLETE SPECIFICATION

Improvements in or relating to Ultra-High Frequency Electrical Transmission Systems

We, PHILCO CORPORATION, a corporation organised under the laws of the State of Pennsylvania, United States of America, of Tioga and C Streets, Philadelphia, Pennsylvania, United States of America, do hereby declare the nature of this invention and in what manner the same is to be performed, to be particularly described and ascertained in and by the following statement:—

This invention relates to a novel wave selector in an ultra-high frequency electrical transmission system, and more particularly relates to a novel wave selector for separating two waves travelling in opposite directions in a wave guide, coaxial or parallel wire transmission line.

In transmission engineering much use is made of the concept of incident and reflected waves. These two waves can exist whenever energy is being transmitted from a generator to a load over a transmission system which may be a wave guide or a coaxial cable or a two-wire transmission line.

The incident wave is a radio wave which travels along the transmission system from the generator to the load, and in so doing carries energy towards the load. The reflected wave is a similar radio wave which travels from the load towards the generator, and in so doing carries energy back towards the generator. Thus the energy which is carried towards the load by the incident wave is divided into two parts at the load. One part is absorbed by the load and the other part is reflected back towards the generator and constitutes the reflected wave.

The energy which is absorbed by the load is useful energy since the load performs some useful function such as radiation of the energy towards a receiving station. On the other hand, the energy which is reflected back towards the generator in the transmission system ordinarily has no usefulness. In fact, it reduces the efficiency of the transmission system by reason of losses which accompany the transfer of energy over a transmission system.

Moreover, the presence of a reflected wave results not only in energy loss in transmitting the reflected energy back to the generator, but there is extra loss in the incident wave since it must carry not only the energy which is to be delivered to the load but also the energy which is to be reflected. This extra energy carried by the incident wave results in additional energy loss in heating the metal of the transmission system.

Thus, if the reflected wave is of a magnitude which is appreciable compared to the incident wave, extra power losses will occur in the transmission system and the efficiency of transmission will be lowered.

The amount of reflection which will occur at the load can be expressed in terms of the impedance of the load as compared to the characteristic impedance of the transmission system. If these are equal, there will be no reflection and thus no reflected wave. If they are unequal, the amount of reflection, as well as the change in phase angle as a result of reflection, will depend on the complex ratio of the load impedance to the characteristic impedance.

When an incident and a reflected wave are both travelling in a transmission system, it is found that they interfere with one another. At each position along the transmission system the amplitude of the field strength will have a value which is different from the value of the amplitude of the field strength at a nearby position slightly displaced along the transmission system. This variation is periodic along the transmission system, having a period of a half wave length, (the wave length being that in the trans-

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mission system being considered) and forming a standing wave pattern along the transmission system.

This pattern has only a small variation from the minimum field strength to the maximum field strength if the incident wave is much stronger than the reflected wave. However, when the reflected wave is almost equal to the incident wave, the ratio between maximum field strength and minimum field strength becomes quite large and a high standing wave ratio is said to exist.

If this standing wave ratio can be measured, the reflection factor can be calculated and the energy travelling in the two directions in the transmission system can be determined.

It has been common practice to measure the standing wave ratio with a device called a "slotted section." In this device, a slot is cut in the wall of the transmission system at an appropriate location in regard to the cross-section of the system. This slot extends along the transmission system for a wave length or so. Projecting into the transmission system through this slot, there is a pick-up antenna or loop which is connected to a detecting and indicating device such as a crystal detector and microammeter connected in series. This probe is so mounted that it can be slid along the slot, so it can explore the variations in field strength which are the standing waves in the transmission system. From the reading of the indicating meter, the maximum and minimum field strengths can be measured and from these figures the amount of power in the incident and reflected waves can be calculated.

This type of measuring device was satisfactory as a laboratory tool in the early development of such systems. However, a need has arisen for a simple measuring device which would indicate the incident and reflected powers without the necessity of any substantial calculations.

In accordance with the invention, a novel wave selector has been developed which provides such a measuring device which is operative over a wide band of frequencies symmetrically located with reference to a central design frequency. In substance, it comprises an auxiliary transmission system placed parallel to the main transmission system for a short distance. These two systems are coupled together at a plurality of points in such manner that the magnitude in terms of field strength of the coupling afforded at the successive points is related in accordance with the relation of the successive coefficients of the expansion of $(a+b)^n$ wherein n is one less than the number of points of coupling. Over the operating band of frequencies some of the incident wave energy in the main transmission system leaks through the coupling into the auxiliary system and induces a wave having a predetermined direction. This wave energy induced at any one of the coupling points is in phase with the wave energy induced at any of the other coupling points.

On the other hand, any wave energy induced in the auxiliary system by the incident wave energy through any one of the coupling points and having a direction of travel opposite from the predetermined direction is 180° out of phase with the induced wave energy in any other of the coupling points and having this same opposite direction of travel. Therefore, wave energy in this opposite direction balances out to zero and only the wave energy having a predetermined direction corresponding to the incident wave which induced it, flows in the auxiliary system.

Likewise, some of the reflected wave energy leaks through the same coupling, enters the auxiliary system, and continues to travel in primarily its original direction. Thus in the auxiliary system, two waves travel away from the coupling in opposite directions without interference. One is proportional to the incident wave in the main transmission system and the other is proportional to the reflected wave in the main transmission system.

Thus, the incident and reflected waves are separated in the auxiliary guide so that they can be individually measured. In order to do this, it is necessary that at each end of the auxiliary guide the crystal detector or other measuring device shall be matched in impedance to the characteristic impedance of the auxiliary transmission system so that there will be no reflections within this system itself.

The most important part of a wave selector is the coupling between the main transmission system and the auxiliary transmission system. If this coupling is not properly designed, the separation of the two waves in the auxiliary transmission system will not be complete, and the device as a whole will have little or no usefulness. This becomes more and more important as the ratio of reflected to incident wave becomes small, because then even a small amount of the incident wave energy travelling in the wrong direction in the auxiliary guide will be interpreted as an indication of a reflected wave in the main transmission system,

and thus there may be a large error in the measurement of the reflected wave energy.

Wave selectors work perfectly only at one frequency; that is, there is only one frequency at which the separation of the incident and reflected waves is complete. If the frequency is different from this frequency, the separation of incident and reflected waves will not be complete, and the indications will be in error. This is particularly true of the indication of a small reflected wave measured in the presence of a large incident wave.

The band width of a wave selector may be described as the amount the frequency may be raised or lowered away from the frequency of perfect operation before the error exceeds a specified amount. For general use it is desirable that a wave selector have as broad a band width as possible.

The improved wave selector described below has features which improve this characteristic and makes our wave selector broad band.

Accordingly objects of the invention are:—the provision of a novel measuring instrument for determining the ratio of the reflected to the incident signal; to provide a novel wave selector in which the incident and reflected waves travel to and operate individual meters; and to provide a novel wave selector having a relatively broad band characteristic for any application requiring separation of two waves travelling in opposite directions in a transmission system.

Other objects of the invention will become obvious from a detailed description which follows in connection with the drawings in which

Figure 1 shows a wave selector system employing one method of coupling in accordance with the invention.

Figure 2 shows two wave guides or transmission systems in which the coupling between the two wave systems is effected by a pair of holes.

Figure 3 is another view of the same coupling plan, but the coupling units are shown as two pairs of holes, totalling four holes.

Figure 4 shows a coupling system using five holes.

Figure 5 shows a coupling system using four holes.

In Figure 2 is illustrated the principle of the invention. This shows a plan view of the junction between the two wave guides, a main wave guide 35 and a secondary wave guide 36. In this junction there are two apertures 31 and 32. These apertures 31 and 32 are placed a quarter of a wave length apart, the wave length being that measured in the two wave guides. Energy from the main wave guide is radiated into the auxiliary wave guide through each of these apertures. If there is only an incident wave in the main wave guide, the energy radiated into the auxiliary wave guide through aperture 31 is 90° ahead in phase of the energy radiated through aperture 32.

The energy radiated into the auxiliary wave guide through aperture 31 propagates in both directions from the auxiliary wave guide. Likewise the energy radiated through aperture 32 propagates in both directions down the main wave guide. In the direction left to right which is the same direction as was the original wave in the main wave guide, these two waves reinforce each other.

However, in the reverse direction, that is, the direction opposite to that in which the energy was flowing in the main wave guide, the two waves in the auxiliary wave guide cancel each other. This arises from the placing of these two apertures in the main wave guide-auxiliary wave guide boundary, a quarter wave length apart and may be explained as follows:

The signal which comes through the left hand aperture 31 spreads both ways down the secondary wave guide. The part which travels to the right reaches the right hand aperture 32 a quarter of a cycle later, since the aperture 32 is a quarter of a wave length away from aperture 31. This is just the length of time it takes the incident wave to travel from the left hand aperture 31 to the right hand aperture 32 in the main wave guide. Thus the signal that leaks through the second aperture 32 and travels to the right is in phase with the signal which leaked through the left hand aperture 31 and travelled to the right.

However, the signal which leaks through the right hand aperture 32 and travels to the left is 180° out of phase with the signal which leaks through the left hand aperture 31. This is because the signal must travel in wave guide 35 as part of the incident wave from the left hand aperture to the right hand aperture, and must then return in the auxiliary wave guide 36 from the right hand aperture to the left hand aperture. This is a distance equivalent to a phase change of half a wave length plus the phase shift in aperture 32 whereas the signal coming through the left hand aperture has to travel a distance equivalent to just the phase shift in aperture

31. This half-wave length difference between the two equivalent distances causes the signals to be out of phase by 180° and thus in the direction right to left, the signals cancel in the auxiliary guide 36.

Thus in the reverse direction there is no propagation in the secondary wave guide. At the right end 37 of the secondary wave guide 36 a suitable measuring device, such as an autobolometer or other convenient measuring device, is used for measuring the received energy. This measuring device preferably matches the impedance of the secondary wave guide and thus prevents any reflected wave therein.

If the wave in the main wave guide were travelling from right to left, the same action would occur but in the reverse direction. That is, the two waves radiated through the two apertures would propagate from right to left in the auxiliary wave guide because they would add in this direction; but in the other direction from left to right in the auxiliary wave guide, they would cancel one another, and therefore there would be no propagation in this direction.

At the left end 38 of the secondary wave guide 36, a suitable measuring device, such as an autobolometer or other convenient measuring device, is used for measuring the received energy. This measuring device preferably matches the impedance of the secondary wave guide and this prevents any reflected wave therein.

If the main wave guide were carrying both an incident and a reflected wave, these two actions described above would be superimposed one upon the other with the result that in the auxiliary wave guide, the wave travelling towards the right away from the pair of apertures would be proportional only to incident wave in the main wave guide, and the wave propagating towards the left in the auxiliary wave guide would be proportional only to the reflected wave in the main wave guide.

Measurements are thus obtained proportional to the incident wave travelling in the main wave guide and proportional to the reflected wave travelling in the main wave guide.

Such a system yields perfect cancellation and addition at one frequency only, and tends to be a narrow band device. Thus, for a 1% change in frequency from the frequency at which the apertures 31 and 32 are exactly a quarter of a wave length apart, the voltages of the signal in the negative direction rise from zero to 3.1% of the voltage in the positive direction. This may cause a very considerable error in the determination of the reflected wave if the reflected wave is small compared to the incident wave.

In order to increase the band width, an identical pair of coupling elements may be placed an odd number of quarter waves length away from the first pair. This is shown in Figure 3. The first pair of apertures, 31 and 32, are placed a quarter of a wave length apart. A second pair of holes, 33 and 34, are placed also a quarter wave length apart. These holes are placed to couple the main and secondary wave guides 39 and 40. Wave guide 40 is provided with suitable measuring devices at 41 and 42 matching the impedance of the secondary wave guide 40.

The distance between holes 31 and 33 is an odd number of quarter waves length. Each of these pairs will independently give perfect cancellation in the negative direction at the frequency at which the spacing between them is exactly a quarter wave length.

However, when the operating frequency is slightly different from the design frequency, there will be a signal in the negative direction from the pair 31—32, and there will also be a similar signal in the negative direction from the pair 33 and 34. However these pairs are then in themselves very nearly an odd number of quarter waves length apart at the new frequency. Consequently there will be a substantial cancellation between the energies being propagated in the negative direction from the two pairs of holes. This cancellation will of course not be perfect since the pairs are not exactly a quarter waves length apart at a frequency other than the designed frequency.

However, if each of the waves in the negative direction from each pair of holes was 3%, a cancellation of 97% of these 3% waves would be effected, and consequently the net result would be a wave in the negative direction of approximately 3% of 3% which makes approximately 1/10 of a per cent. of energy being transmitted in the negative or wrong direction. Thus this would considerably improve the operation of the system.

In order to make this system as wide band as possible it is desirable to make the distance between the two pairs of holes as small as possible. The smallest possible such distances would be a quarter waves length. This would result in hole 33 being superimposed on hole 32. This means that the combined hole

would of necessity have to be larger than either of the other holes. Such an arrangement is shown in Figure 1. Hole 23 is now a hole corresponding in function to hole 31. Likewise hole 26 is a hole which corresponds in function to hole 34. Hole 27 is one which acts as the addition of hole 32 and hole 33. Its coupling effect is twice as large as the coupling effect of either hole 23 or hole 26. Then it can be looked upon as a four element system in which the two middle elements coincide.

In this figure again, the main wave guide 21 carries energy from a generator at the left to a load at the right. As will now be clear, the trio of holes 23, 26 and 27 are especially placed and are so arranged that an incident wave travelling from left to right in the main wave guide will induce a wave travelling from left to right in the auxiliary wave guide. This wave will end in termination 24, and since this termination may be substantially perfectly matched to the auxiliary wave guide, there will be no reflections from it. Likewise, the reflected wave travelling from right to left in the main wave guide will induce a wave travelling from right to left in the auxiliary wave guide. This wave will end in termination 25 and since this termination may be substantially perfectly matched to the transmission characteristic impedance of the auxiliary wave guide, there will be no reflections from termination 25. Thus the energy received by 24 will be proportional to the incident wave travelling in the main wave guide, and the energy received by 25 will be proportional to the reflected wave travelling in the main wave guide.

In order to further improve the band width, another four element system degenerated into a three element system may be introduced an odd number of quarter waves length away from the original three element system. Again the sets of holes of this new system should be preferably at the minimum number of odd quarter waves length displaced from each other. The net result is the four hole system of Figure 5, in which the signal transmitted by the successive holes are in the ratio 1—3—3—1. That is, hole 51 will cause a certain amount of signal (expressed in terms of field strength and not in terms of power) to leak from the main wave guide into the auxiliary wave guide 56. Hole 52 will cause three times this amount of signal to leak into the auxiliary wave guide. Hole 53 will again excite three times the amount of signal in the auxiliary wave guide that hole 51 caused; and hole 54 causes the same signal in wave guide 56 that hole 51 caused. Such a system will have still a broader band width than will the system of Fig. 1.

Such process of adding new systems of elements may be continued indefinitely. The relative amplitudes of the signal transmitted by the various elements is given by the co-efficients of the binomial expansion of $(a+b)^n$. Thus, a four element system is represented by the series of numbers 1—3—3—1. A five element system by the series 1—4—6—4—1. A six element system by the series 1—5—10—10—5—1 and so on. Theory shows that with each added hole, the directivity is improved by approximately 34 d.b. for a frequency deviation of 6/10 of a per cent. from the frequency of perfect operation.

A five hole system is shown in Figure 4. Hole 61 transmits a certain voltage to the auxiliary wave guide 66. Hole 62 transmits a voltage four times as large as hole 61 does. Hole 63 transmits a voltage six times as large as hole 61 does. Hole 64 transmits a voltage four times as large as hole 61, and hole 65 transmits a voltage equal to the voltage transmitted by hole 61. All of these holes are spaced a quarter of a waves length apart at the center frequency, and at this frequency this system gives substantially no wave in the wrong direction whatsoever. The more holes which such a system uses, the better will be the directivity of the waves in the auxiliary wave guide at frequencies differing slightly from the design center frequency. Practically, it turns out that five holes are as many as are needed in the present state of the art in view of the fact that it is impossible under present arrangements to perfectly match a load such as 24 or 25 in Figure 1 to a wave guide such as auxiliary wave guide in Figure 22, to better than about 1% over a reasonably wide band of frequencies.

Mismatch of these terminations causes difficulties which cannot be overcome by the method of coupling between the wave guides. Thus, in Figure 1 a mismatch at termination 24 of 1% will reflect an amount of voltage of 1% of the incident voltage towards the termination 25. Most of this will be absorbed in termination 25, and consequently termination 25 or the indicator attached to it will give a false indication showing that apparently there is a 1% reflected wave in the main wave guide, when actually there may be none. Thus before more than five holes can reasonably be used in the junction wall between the two wave guides, im-

provements must be made in the method of terminating a wave guide over a band of frequencies.

As will now be clear, our invention broadly comprises two transmission systems, at least one of which contains a source of signal, which are coupled together by a plurality of couplers and/or a plurality of groups of couplers, with each coupler or groups of couplers spaced an odd number of quarter wave lengths (measured in the transmission systems) apart, (preferably one quarter wave length), and with the amount of coupling (measured in terms of voltage, current, or field strength, etc.) afforded by the successive couplers or groups of couplers being related by the successive co-efficients of the binomial expansion of $(a+b)^n$, where n is one less than the number of coupling or groups of coupling elements.

By the use of couplers spaced a quarter wave length apart, induced energies in one direction are additive at the several couplers and induced energies in the opposite direction balance out. It will now be apparent that such a result may also be secured by other means than spacing of the coupling points such as the use of retarding and delay networks.

Thus the two transmission systems are coupled in such a manner that over a broad band of frequencies near the design center frequency, the second transmission system has set up in it from the first transmission system, which contains the source of energy, two signals travelling in opposite directions, away from the group of coupling elements or group or groups of coupling elements, each of which induced signals has an amplitude proportional to the amplitude of the two signals travelling in the first transmission system.

The directivity of the system may in some cases be enhanced somewhat by employing for each coupling element that type of element which in itself gives a certain directivity. Such a coupling element is exemplified by a hole in the large dimension of a wave guide spaced somewhere between the center of the guide and the edge.

Although this system has been described with respect to wave guides, it is perfectly possible to use exactly similar methods wth coaxial transmission lines or with two wire transmission lines, or with artificial transmission lines employing lumped constants. The coupling units need not be holes; they may be any well known coupling element such as small coupling loops or small antenna probes, or any resistive or reactive elements. The system will work satisfactorily as long as they are properly phased, and as long as the relationship between the strength of the voltages induced is maintained in accordance with the binomial theorem co-efficient as explained above.

Many variations and modifications of the invention within the scope thereof should now be obvious to those skilled in the art.

Having now particularly described and ascertained the nature of our said invention and in what manner the same is to be performed, we declare that what we claim is:—

1. An ultra-high frequency electrical transmission system comprising a succession of elements spaced apart an odd number of effective quarter wave lengths of the signal frequency and coupling a first transmission system to a second transmission system, the magnitude in terms of field strength of the coupling afforded by the successive coupling elements being related as the successive co-efficients of the expansion of $(a+b)^n$ wherein n is one less than the number of coupling elements.

2. A system according to claim 1 wherein the first transmission system is a main wave guide, the second transmission system is an adjacent auxiliary wave guide, and the coupling elements are arranged to conduct energy through adjacent boundaries of said wave guides at points spaced therealong.

3. A system according to claim 2 wherein the coupling elements comprise holes having progressively varying areas such that the magnitude of coupling afforded by the successive holes varies in accordance with the relation of the co-efficients of the binomial expansion set forth in claim 1.

4. An electrical system substantially as hereinbefore described with reference to the accompanying drawings.

Dated the 3rd day of April, 1946.

For: PHILCO CORPORATION.

Stevens, Langner, Parry & Rollinson,
Chartered Patent Agents,
5/9, Quality Court, Chancery Lane,
London, W.C.2, and at
120, East 41st Street, New York, U.S.A.

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628,547 COMPLETE SPECIFICATION 1 SHEET

[This Drawing is a reproduction of the Original on a reduced scale.]

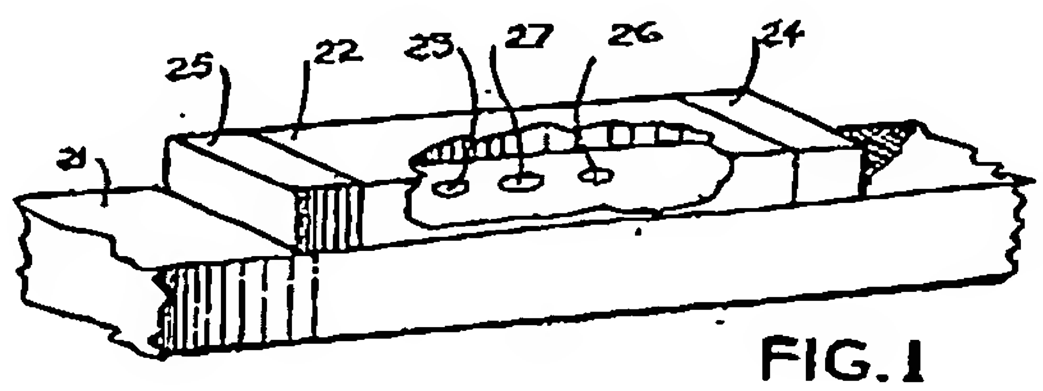

FIG. 1

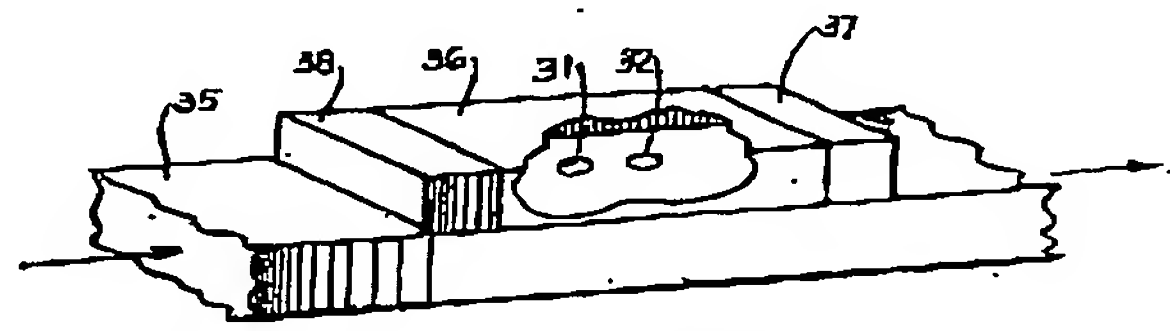

FIG. 2

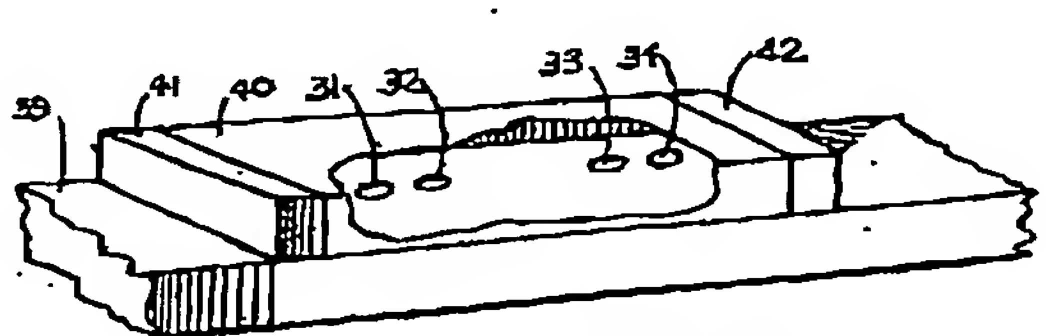

FIG. 3

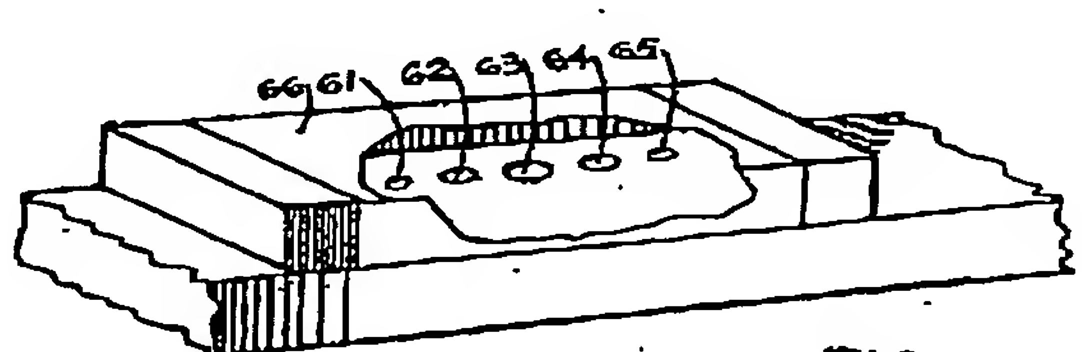

FIG. 4

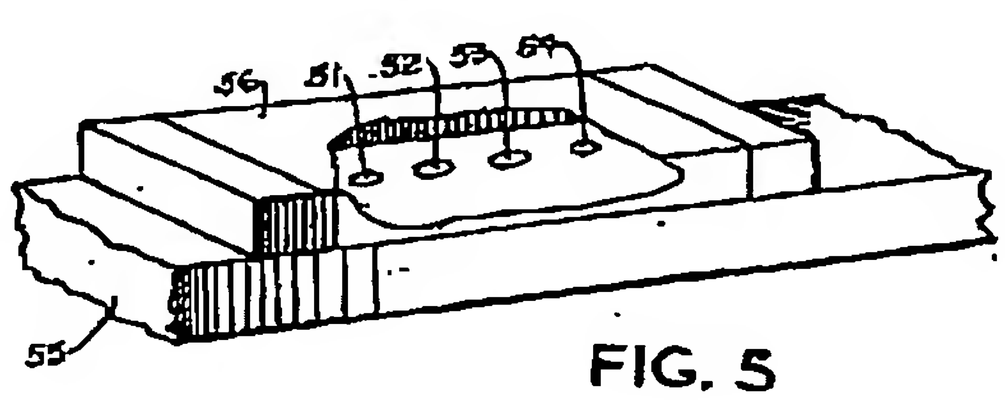

FIG. 5